Temporal nulling of induction from spatial patterns modulated in time

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TEMPORAL NULLING OF INDUCTION FROM SPATIAL PATTERNS MODULATED IN TIME

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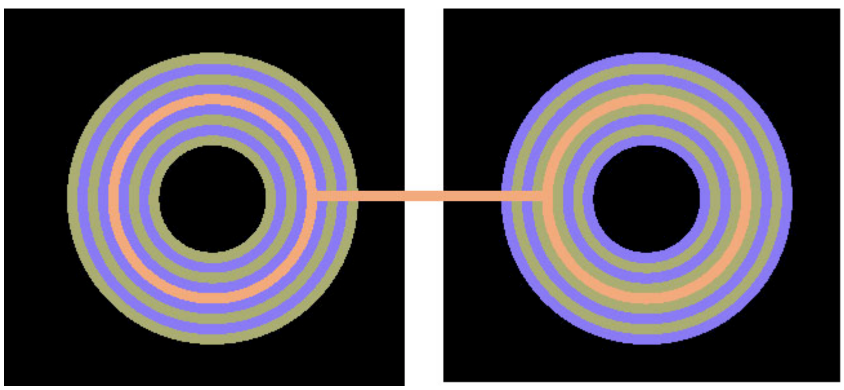
ABSTRACT

Asymmetric color matching demonstrates that receptive-field organization accounts for large color shifts induced by chromatic patterns (Monnier & Shevell, 2003, 2004). Here, we used temporally-varied chromatic inducing light to infer receptive-field organization using a method that does not require color matching. The shifts in color appearance from temporally varied inducing light were consistent with the same *+s/-s* spatially antagonistic neural receptive field described in previous work. The response of this type of receptive-field, which is found only in the visual cortex, increases with S-cone stimulation at its center and decreases with S-cone stimulation in the surround. The measurements also showed a negligible influence of temporal inducing frequency from 0.5 to 4 Hz.

INTRODUCTION

Previous experiments demonstrate that a cortical, spatially antagonistic receptive field accounts for both chromatic assimilation and contrast, depending on the properties of the contextual inducing light (Monnier & Shevell 2003, 2004). An example of the large color shifts implied by this receptive field is illustrated in Fig. 1. The two test rings (linked by the horizontal bar) appear different but they are physically identical. A *+s/-s* spatially antagonistic receptive field explains the test's appearance shift toward the contiguous chromaticity and away from the non-contiguous chromaticity. The present study extends previous work by testing whether this spatially antagonistic cortical receptive field also accounts for the test's percept with temporally varying inducing patterns. In this study, the observer judged only whether the test ring's appearance was steady over time; no judgment of color was required.



(a) *(b)*

Figure 1: Induction from a chromatic pattern. The two test rings (connected by a horizontal bar) are physically identical.

Specifically, we measured how temporal variation in a surrounding area affected the appearance of the test ring. There were three aims of the study. First, the cortical receptive field inferred from color matching (Monnier & Shevell, 2004) implies that temporal modulation very near the test should result in induced assimilation (that is, a shift in test appearance in phase with the appearance of the temporally varying inducing light). Similarly, temporal variation some distance from the test should result in induced contrast (out of phase with the inducing light). These predictions were tested. Second, the amplitude of induced color change from nearby and more remote inducing light was compared. Third, the amplitude of induced color change from temporally varying stimuli was compared to the magnitude of color shift from a steady chromatic background pattern. Overall, the results were consistent with the *+s/-s* cortical receptive field inferred from color matching.

METHODS AND DESIGN

With a *+s/-s* receptive-field of the size described previously, with peak sensitivity near 1 cpd (Monnier & Shevell, 2004; Shevell & Monnier, 2005), temporal modulation in a region very near the test field directly changes the cell's response to light in the test area. This would cause time-varying chromatic assimilation to the nearby light. On the other hand, temporal modulation within the receptive-field surround inversely affects the response in the test area, so the test's percept would change inversely with the surrounding modulation. In the experiments here, the chromatic induction was nulled by adding a time-varying light within the test area. The phase and amplitude of this light were adjusted by the observer to null the perceived temporal variation in the test.

The surround was composed of concentric circles temporally alternating between two chromaticities (Fig. 1). The whole stimulus was composed of a test ring flanked on each side by 4 concentric circles, alternating between chromaticities initially appearing "purple" and "lime". The left pattern in Fig. 1 is called the purple-lime pattern (purple-appearing chromaticity adjacent to the test) and the right pattern the lime-purple pattern (lime-appearing chromaticity adjacent to the test). Both purple-lime and lime-purple patterns were used in the experiments. For each pattern, either the contiguous or non-contiguous chromaticity, but not both simultaneously, was temporally modulated. The pattern's inner and outer diameters were, respectively, 1.8 deg and 4.5 deg, and the spatial frequency was 3.3 cycles per degree.

The stimuli were specified in a cone-based two-dimensional chromaticity space (MacLeod & Boynton, 1979) characterized by relative L-cone to M-cone stimulation [*l*=L/L+M] and relative S-cone stimulation [*s*=S/(L+M)]. The unit of *s* is arbitrary and normalized here to 1.0 for equal energy white. The inducing chromaticities differed in only S-cone stimulation: *l,s,Y* of 0.66, 0.16, 15cd/m^2 for the lime circles, and *l,s,Y* of 0.66, 2.00, 15cd/m^2 for the purple circles. The test ring's chromaticity was set to *l,s,Y*= 0.66, 1.08, 20cd/m^2.

In various conditions, either the contiguous or noncontiguous chromaticity was temporally varied sinusoidally between S/(L+M) of 0.16 and 2.00. L/(L+M) was held constant at 0.66. The observer's task was to adjust the test ring's sinusoidal modulation amplitude in the *s* direction, and its phase (in phase or out of phase with the inducing light), in order to null the perceived temporal modulation in the test ring induced by the time varying part of the surround. Unlike Monnier and Shevell's experiments, no color judgment was required. Observers were able to report any cases for which a satisfactory null could not be achieved (7% and 12% for observers A.T. and F.A., respectively).

The three test chromaticities appeared white, green or pink when viewed alone. Their *l,s,Y* chromaticities were respectively 0.62, 1.08, 20 cd/m2; 0.66, 1.08, 20 cd/m2; and 0.70, 1.08, 20 cd/m2. Four temporal inducing frequencies were tested: 0.5, 1, 2 and 4 Hz.

Three observers took part to this study. All had normal acuity as well as normal color vision as tested by the Ishihara plates and Rayleigh matching. Each observer completed training sessions before the data collection began. Each stimulus was presented three times to the observer in separate experimental sessions. Due to measurement variability, results from one of the three observers were discarded. The median standard error for both observers A.T. and F.A. was 0.08. The corresponding value for the third observer, whose results were discarded, was 0.15 (90%ile standard error 0.30).

RESULTS

Contiguous-chromaticity temporal modulation

Temporal variation of the contiguous chromaticity was predicted to shift test appearance in-phase with the inducer (assimilation), so the required nulling modulation to make the test appear steady should be out-of-phase with the inducer. The required nulling amplitude for the three test chromaticities is plotted in Fig. 2 for temporal frequencies of 0.5, 1, 2 and 4Hz. In these plots, a negative amplitude represents test-field modulation out-of-phase with the inducing light (chromatic assimilation). Each row shows results for a different observer.

The results show that assimilation is found for both types of background (purple-lime and lime-purple) at all temporal frequencies when the contiguous chromaticity is temporally modulated.

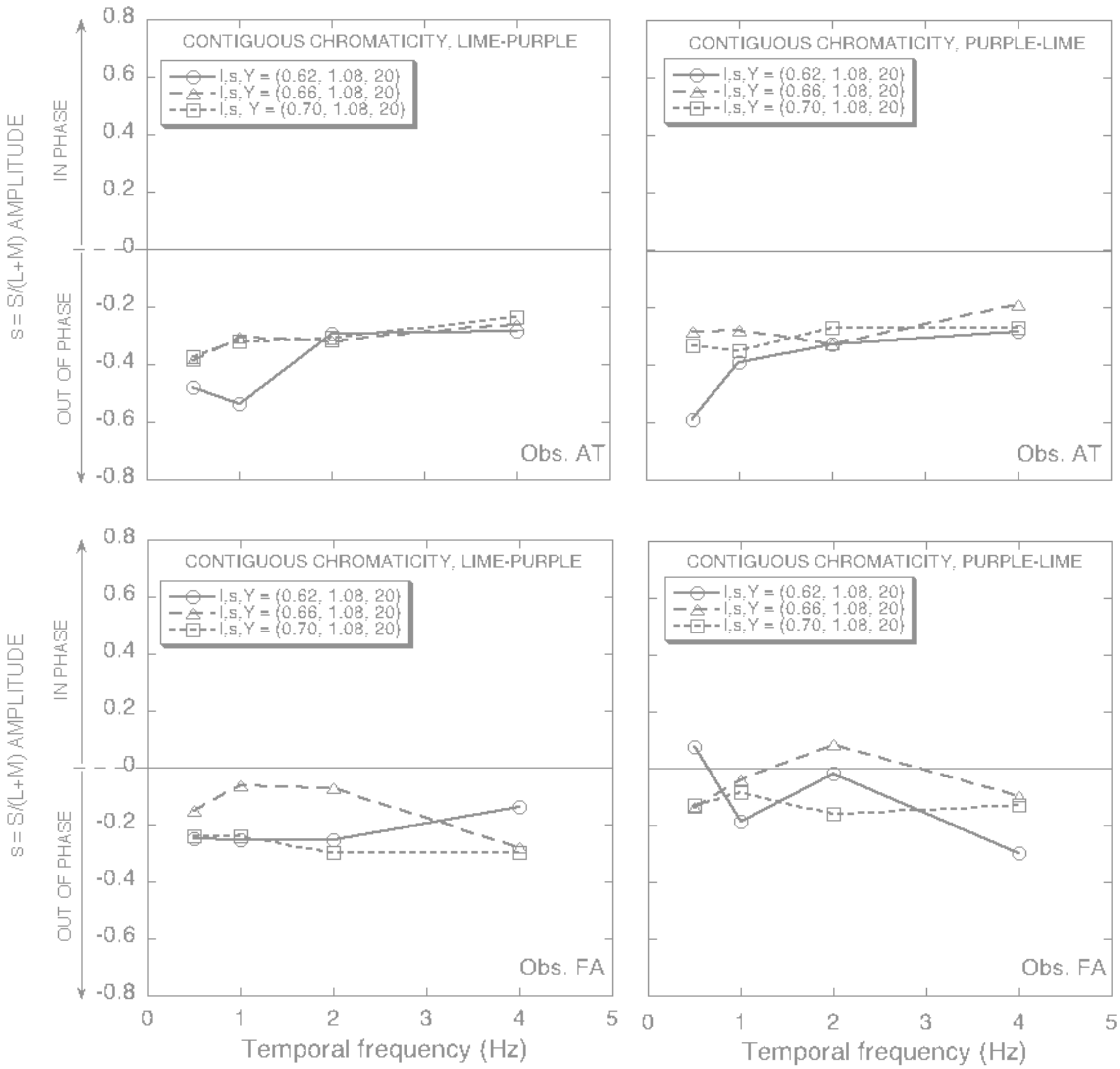


Figure 2: The test-field nulling modulation with contiguous-chromaticity temporal modulation. The nulling amplitude in the S/(L+M) direction is plotted as a function of temporal frequency, for three test-ring chromaticities. The left and right panels show results with purple-lime and lime-purple background patterns, respectively. Each row shows results for a different observer.

Non-contiguous chromaticity variation

Temporal variation of the noncontiguous chromaticity was predicted to shift the test's appearance out-of-phase with the inducer (chromatic contrast) so the required nulling modulation in the test should be in-phase with the inducer. Figure 3 shows for two observers the required test-ring nulling amplitude. In these plots, a positive amplitude represents test-ring modulation in-phase with the inducing modulation, which implies chromatic contrast.

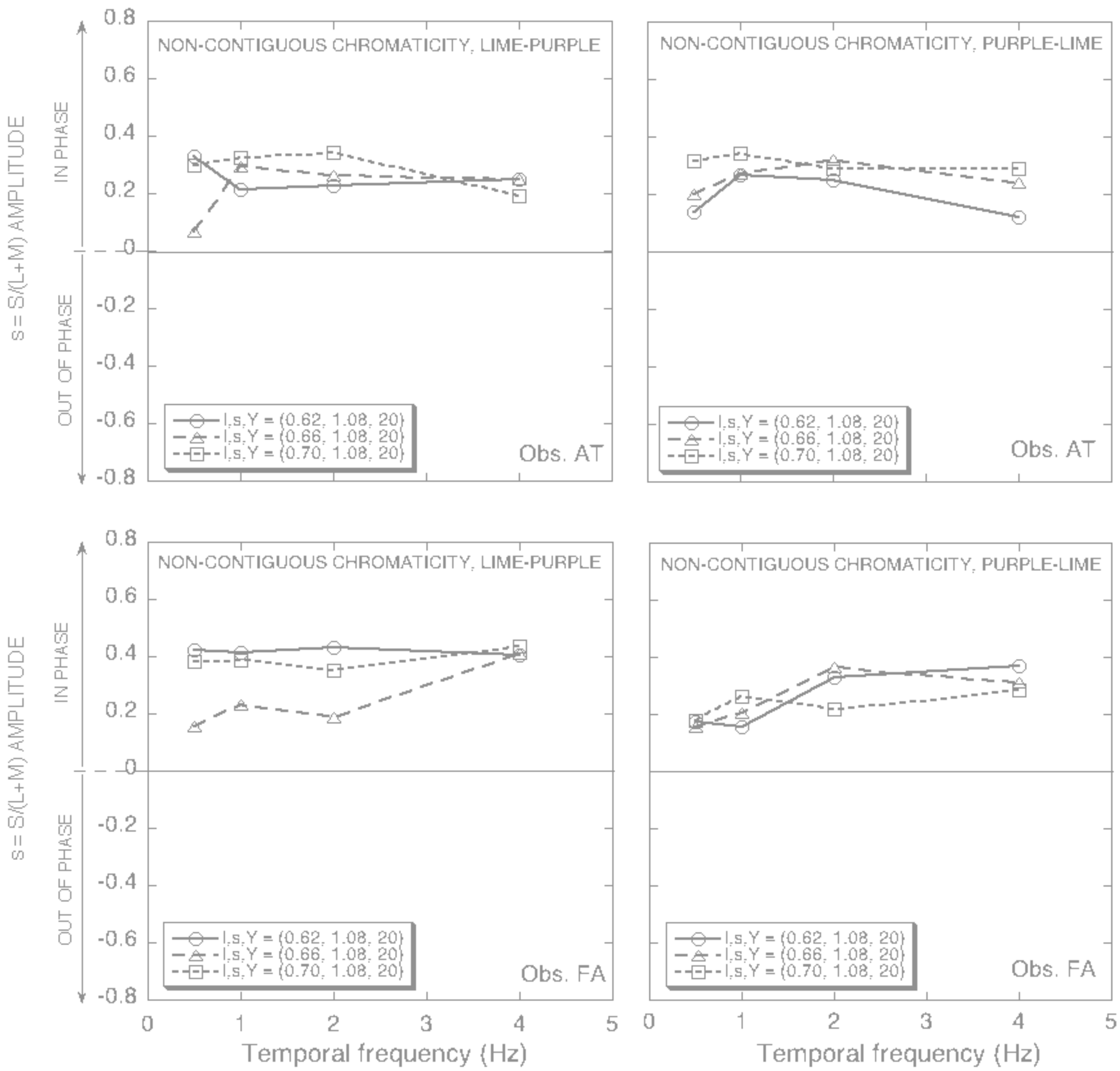


Figure 3: The test-field nulling modulation with non-contiguous-chromaticity temporal modulation. The nulling amplitude in the S/(L+M) direction is plotted as a function of temporal frequency, for three test-ring chromaticities. The left and right panels show results with purple-lime and lime-purple background patterns, respectively. Each row shows results for a different observer.

The results show that modulating the non-contiguous chromaticity causes chromatic contrast, for both types of backgrounds (lime/purple and purple/lime) at all temporal frequencies.

On average over both observers, the results show approximately the same inducing magnitude for both nearby and more remote inducing-light temporal modulation. Figure 4 (solid bars, left versus right panels) compares contiguous-chromaticity and non-contiguous-chromaticity modulation for both types of background patterns (lime-purple and purple-lime). The average contiguous-chromaticity and non-contiguous-chromaticity nulling amplitudes are 0.20 and 0.23, respectively.

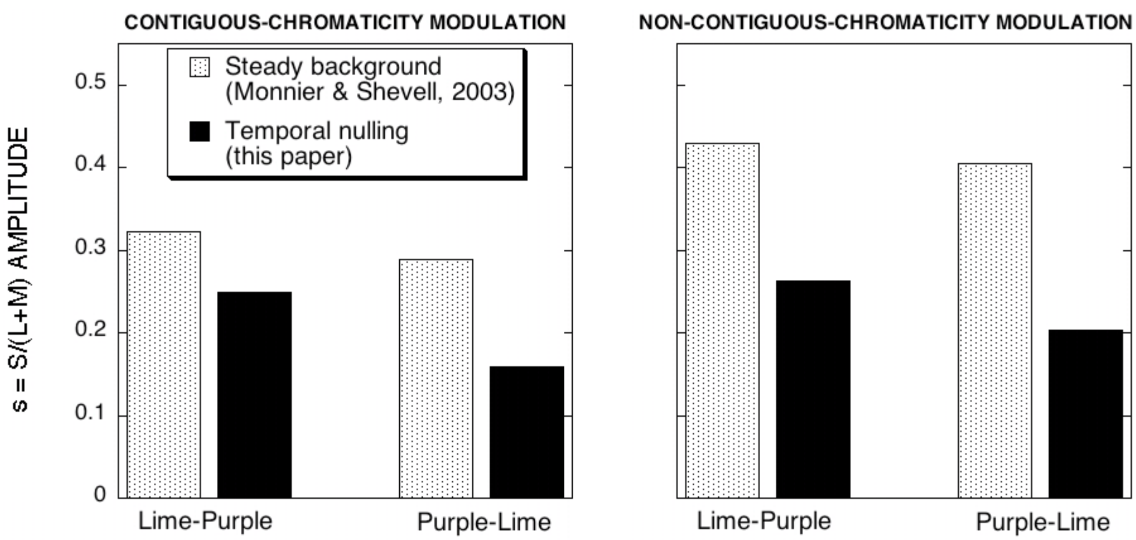


Figure 4: Comparison of the induced s=S/(L+M) amplitude for temporally modulated (black bars) and steady (stippled bars) surrounding patterns. The left panel shows results for contiguous-chromaticity modulation (absolute value of amplitudes shown); the right panel shows results for non-contiguous-chromaticity modulation.

Chromatic induction measured here by nulling modulation was consistent in sign but somewhat smaller in magnitude than found previously with asymmetric color matching of the test ring within a steadily presented patterned background (Monnier & Shevell, 2003). The comparison of the magnitudes of induction from temporally modulated versus steady inducing patterns is based on the amplitudes measured here, averaged over observers and over the three test-ring chromaticities. Results with steadily presented backgrounds (from Monnier & Shevell, 2003) also were averaged over test chromaticities and observers. Recall that with the lime-purple pattern the temporal modulation of the contiguous chromaticity had as extremes the lime-purple pattern shown in Fig. 1 (right panel) and a uniform purple surround. Thus, the appropriate comparison between this temporal modulation and the steady background case is the difference between matches with a steady lime-purple background and a steady uniform purple background. This reasoning was applied also to the other conditions to compare temporally modulated versus steady magnitudes of chromatic induction. For example, for the purple-lime background and non-contiguous-chromaticity modulation, the difference was taken between the matches with the steady uniform purple background and the steady purple-lime background.

A comparison between the two studies shows a lower magnitude of induction for temporally modulated backgrounds than for steadily presented inducing circles (black versus stippled bars, Fig. 4). Though the test ring's chromaticity is slightly different in the two studies (*s* chromaticity here of 1.08 compared to 0.98 with the steady backgrounds in Monnier & Shevell, 2003), the Michelson S-cone contrast (0.85) in the patterned backgrounds is the same in both studies.

CONCLUSION

The results showed that contiguous-chromatic temporal modulation required an out-of-phase nulling modulation of the test ring, implying assimilation from the inducer, and that non-contiguous-chromaticity modulation required in-phase modulation of the test ring, implying contrast. This is precisely the temporal variation in the test's color appearance expected for a *+s/-s* spatially antagonistic receptive field inferred previously from asymmetric color matching (Monnier & Shevell, 2003, 2004). The experiments here also showed that increasing temporal frequency from 0.5 to 4Hz did not appreciably affect the induced color shifts. Overall, these results, which required an observer only to null a temporally varying percept (not to judge its color), corroborate the *+s/-s* cortical receptive field inferred in previous work.

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